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TECHNICAL NOTE

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A FLIGHT STUDY OF THE CONVERSION MANEUVER OF A TILT-WING VTOL AIRCRAFT

By Lovic P. Thomas III

Langley Research Center
Langley Field, Va.

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A FLIGHT STUDY OF THE CONVERSION MANEUVER OF A TILT-WING VTOL AIRCRAFT

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SUMMARY

The tilt-wing vertical-take-off-and-landing aircraft is able to perform essentially continuous slow level-flight conversions with no major longitudinal trim changes. Studies have shown that the explanation of this ability lies in the shift with wing incidence of the curves of longitudinal stick trim position plotted against airspeed and the direction of the slopes of these curves at intermediate wing incidences. These characteristics will suggest how the wing incidence should be varied during conversion to avoid large pitching moments.

No large amount of transient longitudinal control was used other than rate-damper induced elevator motions during short-period oscillations. Also, the previously mentioned constant-stick-at-neutral trim position left a maximum amount of control available for corrections in both directions during the transition conditions investigated.

Prohibitive power variation, which would be reflected in the need for excessive pilot attention to propeller pitch control, was not noted.

Transitions for other than level flight and other than favorable weather and visibility are not investigated herein.

INTRODUCTION

Several types of vertical-take-off-and-landing (VTOL) aircraft have been designed and built to investigate the VTOL concept. The National Aeronautics and Space Administration is taking part in this test-bed program as a continuation of its interest in the VTOL concept. This paper reports on one aspect of the program on a tilt-wing type, the VZ-2 (Vertol 76) aircraft.

A major problem area in the VTOL concept has been the flight regime between hovering flight and conventional airplane flight, that is, the conversion maneuver. The ability of the tilt-wing VTOL to accomplish this maneuver has been documented by fairly complete instrumentation. Some of the longitudinal data were analyzed first and are incorporated in this report because it is felt that such data best describe the fundamentals of the conversion maneuver.

The data herein were obtained with the cooperation of Vertol Aircraft Corporation.

APPARATUS AND PROCEDURE

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Aircraft

The VZ-2 vertical-take-off-and-landing flying test-bed incorporates a tilting wing-propeller assembly. Physical dimensions of the aircraft are given in table I and a three-view drawing is given in figure 1. Figure 2 is a photograph of the aircraft in transition.

Longitudinal control is obtained from an all-movable horizontal-tail surface plus a tail fan capable of producing a pitching moment, and directional control is obtained from a conventional rudder plus a yaw fan. The blade angles of these fans are controlled by direct linkages with their related control surfaces. Differential propeller pitch supplies lateral control when the wing is in hovering position, and conventional ailerons become effective when the wing is in the conventional forward-flight position. A mechanism phases one lateral control in and the other out as the wing tilts through intermediate positions. The wing incidence control is actuated by the pilot by means of a push-button through which the wing incidence can be changed at either a constant rate or intermittently at his discretion. The pilot's primary power control is a helicopter-type collective pitch lever controlling the pitch of the two propellers. A governor holds the propeller speed at about 1,410 rpm.

The aircraft is equipped with pitch- and roll-rate dampers that sense angular velocities through gyros and initiate control deflections tending to damp the aircraft pitching and rolling motions. These dampers may be turned on or off by the pilot.

Instrumentation

The combination of NASA and manufacturer's instrumentation used included potentiometers to measure control positions, flow direction vanes on a boom to measure angles of attack and sideslip, gyro turn-meters to measure the three angular velocities, and a shielded total-pressure head plus a swiveling static-pressure head located on the boom to measure airspeed. The data from the instruments were recorded by an NASA 36-channel oscillograph, except for the airspeed in the low-speed range (0 to 40 knots) which was recorded by an NASA mechanical optical pressure recorder.

The airspeed head is designed to yield a resultant flow velocity up to angles of 40° from the longitudinal axis of the aircraft. The installation was not calibrated, but the static-pressure error due to the aircraft bubble was corrected for by using information from reference 1.

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Test Conditions

The primary object of this paper is a longitudinal control study of a nearly constant-altitude slow conversion performed by a tilt-wing VTOL aircraft under favorable weather and visibility conditions. Gradual speed variations about a fuselage nearly level condition at five fixed-wing incidences were performed to reveal some of the aircraft longitudinal control characteristics and add insight into the technique of flying the aircraft through transition. Since it was decided to fly these runs low and level, no constant-power runs were attempted. The range of wing incidence for the conversion time history presented was from about 82° to 20°, and the range of wing incidence explored using the slow speed variations was from 75° to 43°.

The aircraft rate dampers were turned off during part of the transition at the higher speeds to investigate the aircraft behavior without artificial damping.

Data Reduction

A time history of a typical level-flight conversion shown in figure 3 was obtained by direct read-up of the records at selected points, plus between point fairing based on detailed inspection of the records in the zones between the points. The gradual speed-variation information (fig. 4) represents faired data and does not reflect scatter due to transient corrections.

RESULTS AND DISCUSSION

The study of records taken during conversion maneuvers performed by the tilt-wing VTOL aircraft showed that the longitudinal control did not depart from near neutral throughout the maneuver. Since high pitching moments were expected and neutral stability at all conditions was unlikely, it appeared that some technique was used such that the pitching moments encountered were small. The results to be discussed indicate that this technique involved adjusting the wing incidence with airspeed such that the pitching moments were kept small.

Trim-Control Considerations

The time history of the conversion in figure 3 shows that a wide
range of wing incidences and airspeeds was traversed with very slight L
longitudinal trim requirements. There seem to be only two trim stick 6
positions: one somewhat aft position for hover, and another approxi- 2
mately neutral position during conversion. 8

Figure 4 shows slopes of stick trim position plotted against airspeed at several wing incidences such that increasing speed requires a forward trend of stick position and also shows that the trim speed becomes rapidly higher as the wing reaches the lower range of incidences covered. These characteristics afford a cue for performing conversion: as the aircraft speed increases at a given wing incidence, the stick trims forward. This forward trend of the stick can be halted momentarily by decreasing the wing incidence, that is, the stick may be returned to an initial position by using another stick-position—airspeed curve. The reverse of this process is true for reducing speed. This technique is desirable in that it tends to keep the pilot from venturing into operational areas in which the aircraft ability to trim is exceeded; it furthermore tends to keep him in trim with approximately neutral controls so that he has nearly half of the total control available in each direction to correct for disturbances.

It will be noted that the curves of longitudinal stick position plotted against airspeed at constant wing incidences shown in figure 4 cover approximately the lower half (up to 43° wing incidence) of the transition speed range. Attention was focused on the lower, rather than the upper, part of the range because the increased effectiveness of the elevator at higher speeds should make the longitudinal control problem less critical. Limited data and experience obtained in the upper half of the speed range indicate a similar picture to that shown in figures 3 and 4, that is, moderate stick displacements over the airspeed and wing incidence range and no excessive variations of stick position with airspeed at constant wing incidence. Similarly, the conclusions of this paper are indicated to be essentially unchanged at the higher wing incidences (74° to 82°) not covered in figure 4.

Transient Control Usage

Large random control displacements were not necessary for corrective purposes. Longitudinal oscillations are apparent, however. (See fig. 3.) There is some indication that the aircraft rate-damper installation is aggravating the oscillations at higher speeds, and therefore the oscillations are believed not to be a fundamental problem. The one-second-period oscillations seem to get worse as the speed increased, up to time of 38 seconds, when the dampers were cut off. The period immediately doubled and the pilot damped the oscillation effectively in

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$1\frac{1}{2}$ cycles. The oscillation was triggered again at a time of about 47 seconds but was damped substantially in about 3 cycles. The rate dampers were turned on again at about 76 seconds and the characteristic one-second-period oscillations immediately resumed, subsiding in amplitude as speed decreased. In general, the transient control usage with rate dampers on exceeded the usage with dampers off. However, it might be added that the rate dampers are of considerable aid during hovering and very low-speed flight.

Control of Engine Power

The time history of engine-shaft horsepower is included to give an indication of the engine power variations in the transition. Power was increased for hovering take-off at the beginning of the record. As the conversion towards airplane flight progressed, the power requirement slowly decreased and vice versa. Transient power changes were about 15 percent of the total available. There is no evidence that these changes required undue attention to pitch control nor that they conflict with available engine characteristics.

CONCLUDING REMARKS

No major trim changes were found during essentially slow continuous level-flight conversion maneuvers performed by the tilt-wing VTOL aircraft under favorable weather and visibility conditions. This lack of trim change is attributed to the shift with wing incidence of the curves of trim position plotted against airspeed and the slopes of these curves at intermediate wing positions. As the airspeed changes during the conversion, it is possible to keep the stick trim position constant (at neutral) by varying the wing incidence in a specific manner; the trend of stick trim position furnishes a cue as to how the wing incidence should be varied.

No large transient longitudinal control was used, other than rate-damper induced elevator motions during short-period oscillations. Also, no excessive power variations were noted.

Problem areas requiring added investigation and documentation relative to level-flight transitions are judged, from experience gained during these and similar tests, to include effects of balked landing, aborted take-off, and gusts on the problem of control during transition; effect of ground proximity on controllability, especially if the rate dampers are not considered fail-safe; and effect of density altitude on adequacy of aircraft control moment.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 7, 1959.

REFERENCE

1. Gracey, William: Measurement of Static Pressure on Aircraft. NACA Rep. 1364, 1958. (Supersedes NACA TN 4184.)

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRCRAFT

Propellers:	
Diameter, ft	9.5
Blade chord, in.	13
Blade twist (linear, root to tip), deg	19.2
Airfoil section	NACA 0009 with 0.5-in. cusp
Blade taper ratio	1
Solidity, $\frac{bc}{\pi R}$	0.218
Distance between propeller axes, ft	14.67
Wing:	
Span (excluding tips), ft	24.88
Chord, ft	4.75
Airfoil section	NACA 4415
Taper ratio	1
Sweep, deg	0
Dihedral, deg	0
Pivot, percent chord	37.6
Ailerons -	
Chord, ft	1.25
Span (maximum), ft	5
Tilt range (referenced to upper longeron), deg	9 to 85
Vertical tail:	
Height, ft	5.43
Chord (above rudder), ft	4
Sweep at leading edge, deg	0
Airfoil section	NACA 0012
Rudder -	
Chord (constant portion), in.	$21\frac{1}{2}$
Span (maximum), in.	58
Horizontal tail:	
Span (less tips), ft	9.90
Chord, ft	3.00
Center section chord, ft	4.21
Sweep, deg	0
Airfoil section	NACA 0012
Dihedral, deg	0
Length (distance from wing pivot to leading edge of tail), ft	10.475
Hinge point (distance from leading edge), in.	8.3
Control fans:	
Diameter (both fans), ft	2.00
Moment arm about wing pivot (both fans), ft	12.35
Number of blades	4
Fuselage length (approximate), ft	25.5
Engine	Lycoming T53
Weight as flown, lb	3,200
Center of gravity (for 9° wing incidence):	
Longitudinal[a], percent chord	32.5
Vertical, in. below wing pivot	≈14
Center of gravity (for 85° wing incidence):	
Longitudinal[a], in. aft of pivot point	0.1
Vertical, in. below wing pivot	≈11

[a]The longitudinal reference line is parallel to upper longeron.

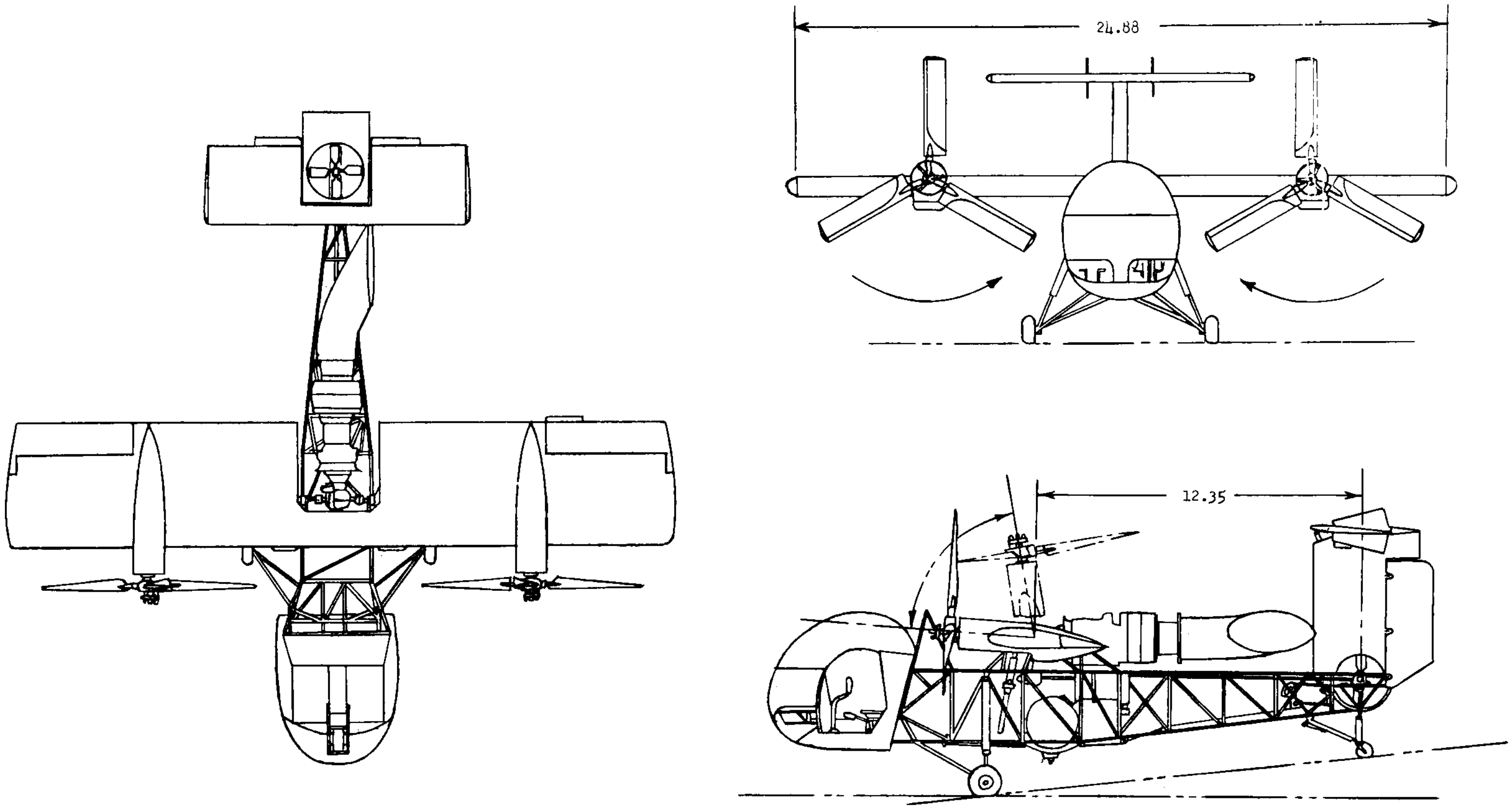

Figure 1.- Sketch of the tilt-wing VTOL aircraft. All dimensions are in feet.

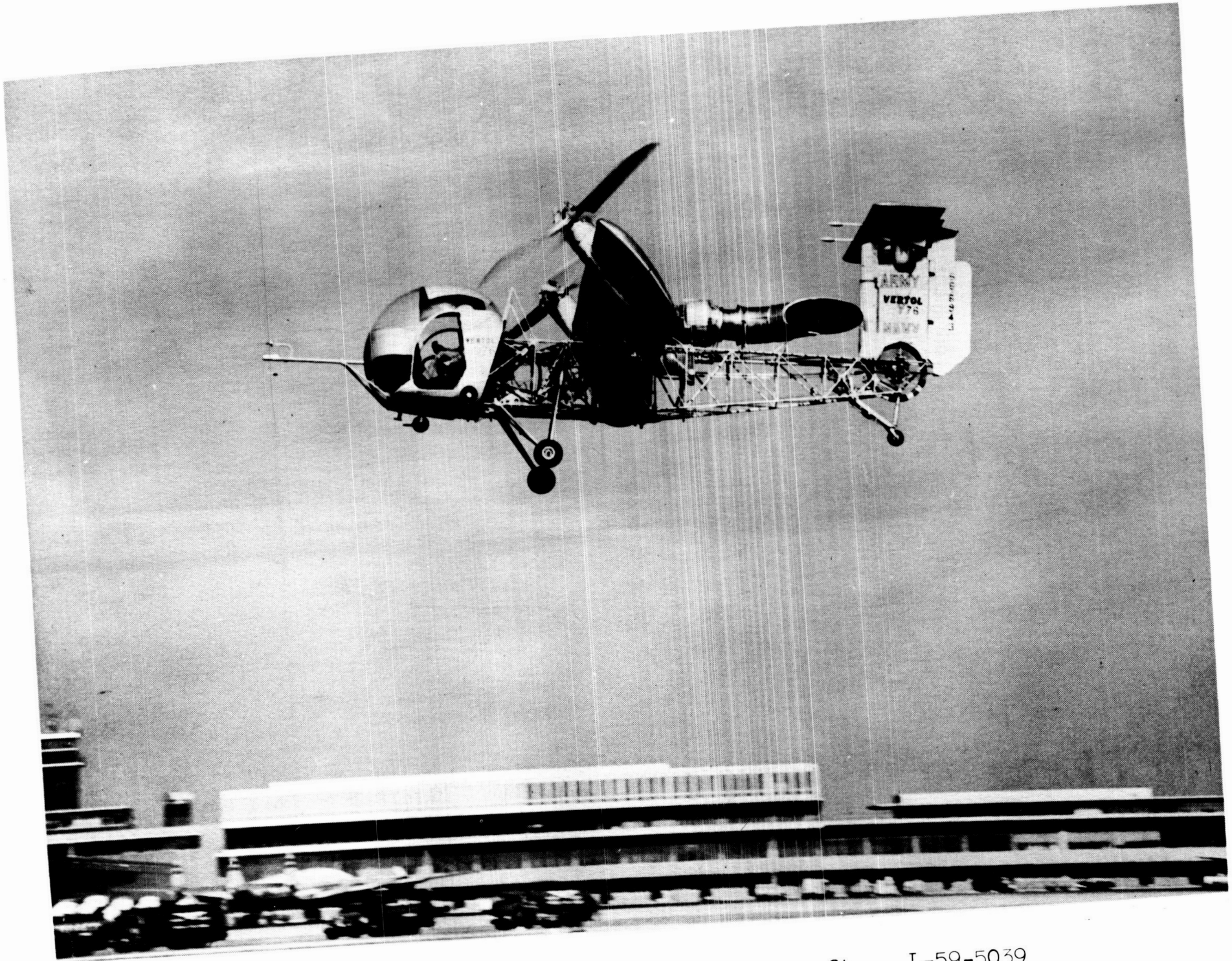

Figure 2.- Tilt-wing VTOL aircraft. L-59-5039

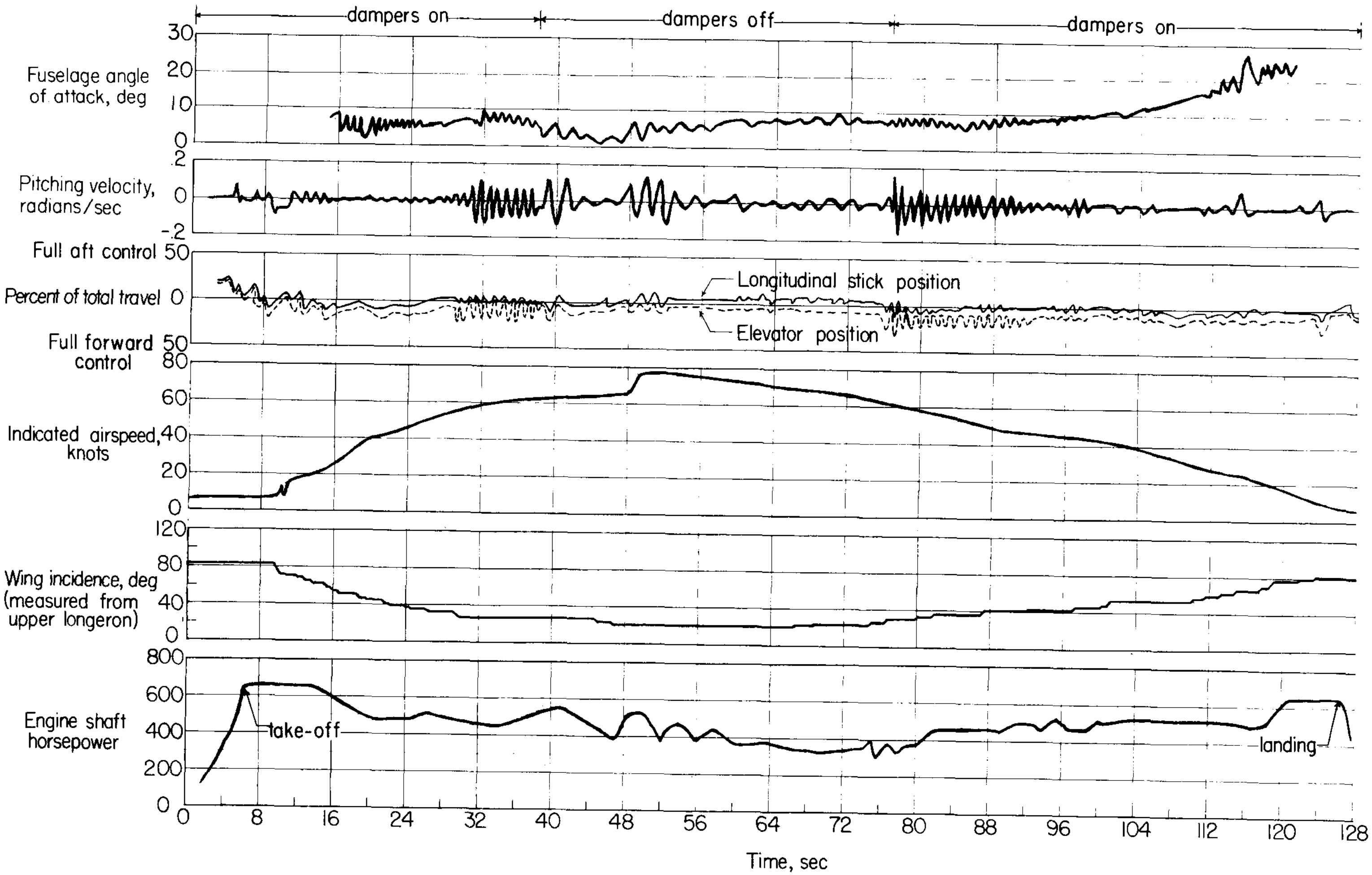

Figure 3.- Time history of typical level-flight conversion performed by the tilt-wing VTOL aircraft.

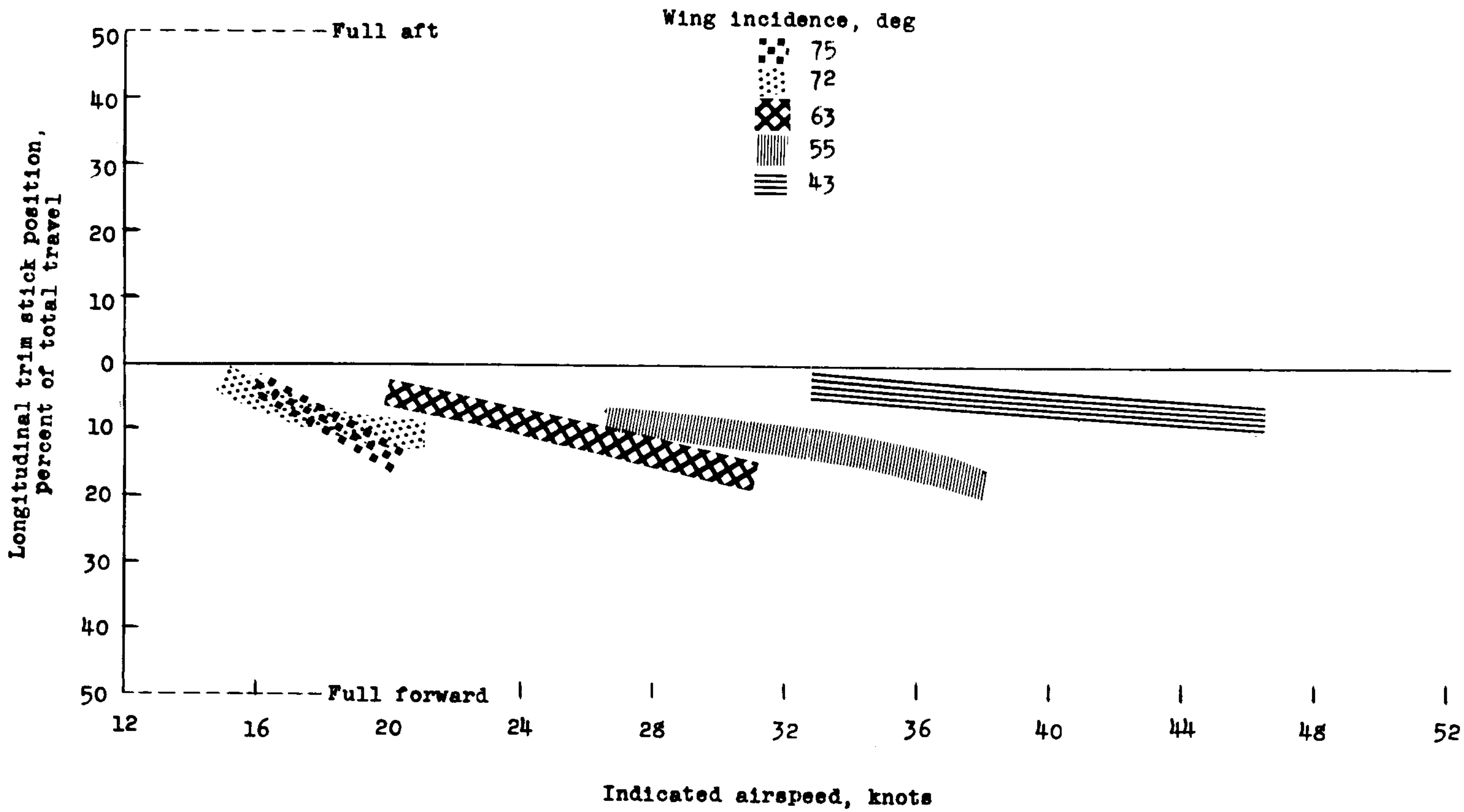

Figure 4.- Longitudinal stick trim variation with airspeed and wing incidence. (No attempt was made to hold constant power.)

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